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Structural Geology of the Holloway Mine, Abitibi Greenstone Belt, Ontario

by

B. Luinstra and K. Benn

2001

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Structural Geology of the Holloway Mine, Abitibi Greenstone Belt, Ontario

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Ontario Geological Survey
Open File Report 6045
2001

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Introduction

INTRODUCTION

Gold deposits associated with major regional shear zones have been known in the Abitibi Subprovince of the Superior Province of the Canadian shield for half a century (Satterly, 1953; Ayer et al., 1999). Many of the large deposits of the Timmins and Val D'Or gold camps are spatially related to the major shear zones. Recently, exploration along the Porcupine-Destor Deformation Zone (PDDZ) east of Timmins, one such regional shear zone, has led to the discovery of two new mines, sparking renewed interest in the region. The Holloway Mine, 87.5 % owned and operated by Battle Mountain Canada Ltd. (BMC), a subsidiary of Battle Mountain Gold Ltd., is one of the recently discovered mines. The nature of the deposit, which has some unpredictable and discontinuous zones of mineralization, led to the initiation of the present structural investigation. This report summarizes the results of the collaborative project involving BMC, the Ontario Geological Survey (OGS) and the University of Ottawa (UO).

The study area is situated 60 km east of the town of Matheson, and 15 km west of Quebec border, just 500 metres north of Highway 101, and 1 km north of Barrick Gold Corporation's Holt-McDermott mine (Figure 1.1). The goals of the study are twofold. First, to identify and describe the major structures within the Holloway mine and to determine their relationship to mineralization. Second, this study identified and described those structures associated with the PDDZ in order to shed new light on its place within the larger tectonic history of the Abitibi greenstone belt. Work began in the summer of 1997 and continued through the summer of 1998, with additional work completed in the summer of 1999. Samples collected during field work were prepared for petrographic examination which was completed over the winters of 1997-98 and 1998-99. A major portion of the work involved underground mapping at scales ranging from 1:500 to 1:2 500. In addition, drill core was relogged with specific focus on collecting structural observations and data. All surface outcrops located with in a 2 km radius of the mine were also examined.

LOCATION AND ACCESS

The Holloway mine is located 500 metres north of Highway 101, 60 km east of Matheson and 15 km west of the Ontario Quebec Border (Fig. 1.1). Access to the mine site is from a gravel road from Highway 101. Several additional roads provide access to the mine property, including the OPP tower road (local name), which runs from Highway 101 north for 2km, on or near the Holloway - Harker Township boundary. As well, an old tractor road that runs to the historic Seagar's Hill claims, west of the mine, curves around the north edge of the mine property. Additional roads on the mine site provide access to outcrops and trenches. Underground investigation was restricted to areas of recent or active development due to safety considerations. During the summer of 1997, the western portion of the deposit between the 415 and 520 metre levels was actively being mined, and the majority of mapping was completed in that area. The eastern portion of the deposit was available for study between the 505 and 650 metre levels during the summer of 1998.

Surface outcrops were located, stripped and bleached over the three summers. Full access was given by BMC to their entire stockpiled drill core. A majority of recent drill core was stored in cross piles at the Holloway mine site, with additional core stored at the former Aunor mine site in Timmins, and the most recent drill core stored at the BMC exploration camp located 4 kms east of the mine, on the shore of Holloway Lake.

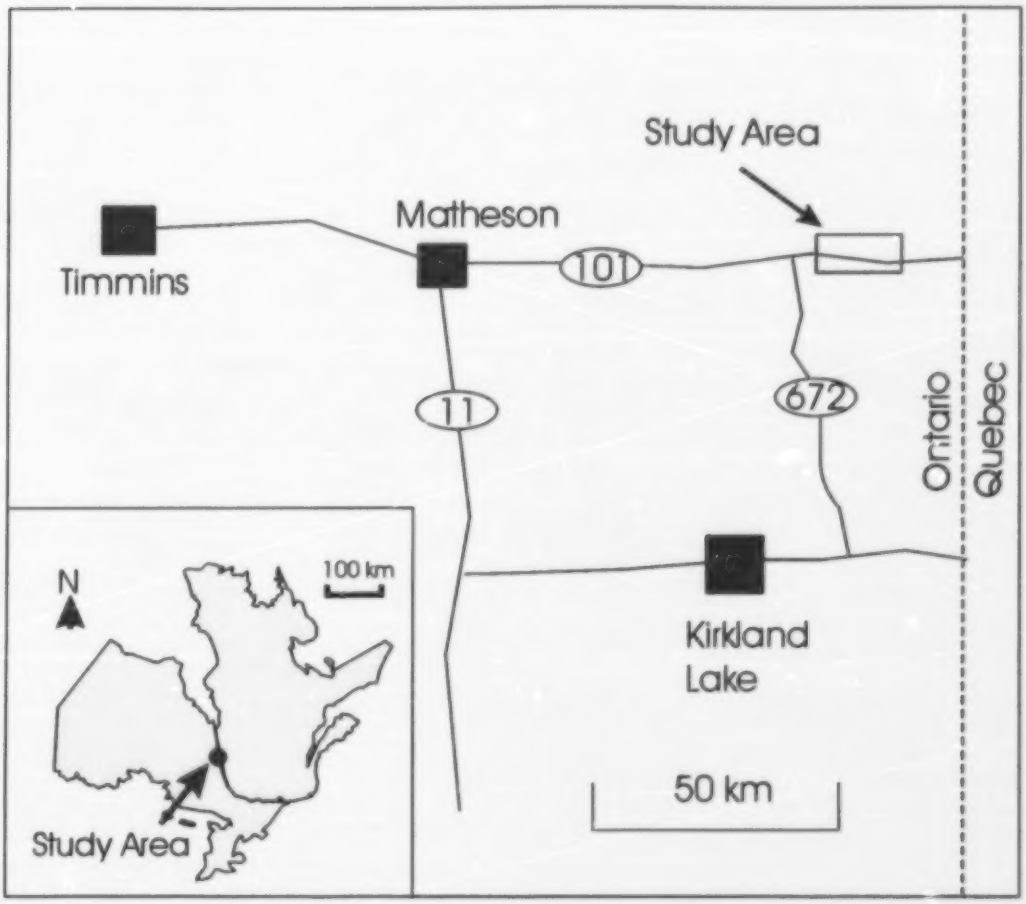

Figure 1.1: Location of the Holloway Deposit.

EXPLORATION HISTORY

The history of exploration in this area is long. Most information gathered for this section was gleaned from internal BMC reports by Broughton et al. (1991) and government reports of Satterly (1953).

The first prospectors known to have explored in the area were in 1907-1908, when Russell Cryderman, William Cooper and William Woodney walked the 10 km distance from the south shore of Lake Abitibi to the 'Lightning River Area', which encompasses the present day Holloway and Holt-McDermott mines. Only sporadic prospecting activity took place until Cochenour and Willans opened up a route from Matheson to the east around 1916, utilizing township boundaries, which had been cleared and surveyed in the early 1900's.

Gold was first discovered in the area in 1917 in the south-west corner of Holloway township by Cochenour and Willans (Broughton et al., 1991). This early gold discovery led to an increase in prospecting activity in the area, and 1922 had staked all of the area. Gold showings were found on the Seagar's and Cryderman claims which together comprise the present Holloway mine site as well as on the McDermott claim, site of the present day Holt-McDermott mine (Satterly, 1953). In 1922, Mining Corp. took control of the Cryderman claim and stripped small outcrops, leading to the discovery of ENE trending mineralized zones. In 1923, several diamond drill holes were drilled to test the horizon at depth but intersected only narrow zones of alteration with poor grades. Further investigation into the claim was abandoned. These holes stopped only metres short of intersecting Holloway's main "Lightning" zone and the property was left idle.

While the Cryderman claim lay idle, the Seagar's claim remained busy for a number of years. A number of pits and trenches were dug following the discovery of the 1922 gold showing, and in 1924 Abitibi Mines Ltd. (AML) was formed to explore the property and in turn discovered the 'Mammoth Vein'. This NNE striking, moderately east dipping quartz-carbonate vein ranged in thickness from 50 cm to 1m, and contained extremely high grades (up to 85 gpt over 0.9 m). Two small shafts were sunk on the vein in 1925, and 3 holes were drilled. Only narrow mineralised zones were found at depth and AML abandoned the property. In 1929, Teddy Bear Valley Mines Ltd (TBL) took control of the property, and in 1934 they deepened one of the pre-existing shafts for underground exploration. Once again, disappointing results were returned and the property was left idle.

In 1980, Lightval Mines Limited optioned the property, and the potential of the area was re-examined. Various geophysical surveys were completed, including ground magnetic, very low frequency (VLF) and electro-magnetic surveys. Additional stripping and some 20 diamond drill holes gave unimpressive results, and the property was again left idle. Renewed investigation began in 1984, with magnetic and induced polarization (IP) surveys completed. Additional 7 holes were drilled to specifically test the geophysical anamolies within the "Lightning" zone stratigraphy, and only narrow mineralized zones were encountered. One hole, however, intersected visible gold in a quartz vein, 30 m below the present day ore zone footwall contact.

In 1985, Noranda Exploration Limited acquired Mining Corporation and took over the Cryderman claim and completed magnetic, VLF-EM and geological surveys. The following year, 3 holes were drilled along the same section that encompasses the present production shaft and intersected the lightning zone. In 1987, drilling continued on both properties testing the Lightning Zone and related stratigraphy. Drilling continued through 1988 and 1989 when Noranda subsidiary, Hemlo Gold Mines Ltd., took over exploration on both properties. Between 1989 and 1993, 55 holes tested the Lightning Zone stratigraphy. (Cooper 1994). In 1993, a 441 metre exploration shaft was sunk on the Lightning zone on

the Holloway mine site. A 750 metre drill drift was constructed, and drilling was undertaken at 25 metre sections. An 8500 tonne bulk sample was also taken from a crosscut and drift. A feasibility survey was completed and identified an undiluted reserve of 5.2 Mt grading 7.9 grams per tonne (Guy, 1996)

Exploration drilling has continued both underground and from the surface in recent years. A 1 km long drill drift was completed on the 750 metre level in the summer of 1999. This recent exploration has predominantly focused on the extension of the Lightning zone both at depth and to the east and west of the deposit.

PREVIOUS GEOLOGICAL STUDIES

Cyril Knight et al (1919) completed a first geological study of the area. More detailed geological survey of the study area followed in 1948 with an Ontario Department of Mines mapping program run by Satterly (1953). As a result of his work, the first geological maps of the area were released at a scale of 1:12 000. The area was re-examined in 1985 as part of an Abitibi wide program (Jensen and Langford, 1985). Jensen and Langford's (1985) work has become an essential starting point for all further investigation in the Ontario portion of the Abitibi. Berger et al (2000) remapped and compiled additional data in the study area.

The first detailed work on the Holloway mine site was undertaken by Noranda Exploration Ltd. and was published as an internal report (Broughton 1991). An additional internal document was compiled in 1994 as part of an in-house evaluation (Cooper 1994). A Master's thesis was completed by Guy (1996) who studied the major lithologies of the mine, and the interpreted role of volcanic breccias in the formation of the deposit. A first order structural analysis of the deposit was completed by Barclay Geological Services, in 1995. This research, prior to commencement of this study, produced a substantial base of knowledge upon which to expand. The need for a detailed structural geology survey of the deposit and a geochemical investigation of the alteration of the area led to the initiation of the present structural study and a concurrent geochemical investigation (Ropchan, in press).

ACKNOWLEDGEMENTS

The authors would like to thank Battle Mountain Canada Limited for financial support and for unlimited access to information, underground workings and drill core. The Ontario Geological Survey provided logistical support and summer employment for the duration of the study. Several individuals have been particularly helpful, Richard Labine, Sylvain Picard, Rick Alcock, Mark Davis, John MacKenzie, Barbara Guimont, Pat Mohn and Sean McCann provided helpful advice and keen eyes and ears at the Holloway mine site. Roger Dahn, Roman Gadzala and Kevin Thompson have been valuable aids in the Battle Mountain Exploration office. John Ayer, Norm Trowell, Phil Thurston, Andy Fyon and Christine Vaillancourt of the OGS have all been of great assistance. Yuri Amelin performed geochronology at the Royal Ontario Museum. The authors were aided by exceptional assistants throughout the project, including Sean Nattress, Kathy Michaud and Chanelle Lepine. Enlightening conversations were held with fellow graduate students at the Ottawa-Carleton Geoscience Centre, University of Ottawa campus, Luc Pigeon and Jean Ropchan. I would like to give special thanks to Robert Jones for his unfailing hard work as my primary assistant. I would also like to thank Ben Berger of the OGS for his excellent conversations and open mind, as well as his exceptional patience.

Literature Review

The Abitibi greenstone belt is situated within the southeastern part of the Archean Superior Province of Canada's Precambrian Shield. The low metamorphic grades, the pristine preservation of the volcanic and sedimentary features, and the abundant mineral resources have attracted worldwide interest, especially amongst volcanologists and economic geologists. This section is intended to provide the reader with a brief overview for this portion of the Abitibi greenstone belt. This includes a brief review of the tectonic models for the Abitibi belt, and includes a specific look at the place of the PDDZ within the models. The metamorphism in the belt and the debate surrounding gold mineralization are also discussed. The usage of the prefix "meta" for all rocks will not be employed with the understanding that all rocks have undergone metamorphism.

REGIONAL GEOLOGY AND TECTONICS

The supracrustal assemblages of the Abitibi Subprovince are dominantly comprised of komatiitic, tholeiitic, and calc-alkalic volcanic rocks which have been grouped into several sequences, or cycles, of volcanism (Dimroth et al., 1982, 1983a b; Jensen and Langford, 1985). The rocks have been locally tilted into steeply-dipping orientations, and they are transected by large regional shear zones such as the Porcupine Destor Deformation Zone (PDDZ) (Fig. 2.1) and the Cadillac-Larder Lake Deformation Zone (CLLDZ). The regional shear zones are spatially associated with Timiskaming-type sedimentary rocks, as well as with alkaline volcanic rocks and intrusions (Dimroth et al., 1982, 1983a,b; Thurston and Chivers, 1990; Mueller et al., 1996).

Early workers established a stratigraphy for the region. Dimroth et al. (1982, 1983a,b) were the first workers to apply modern tectonic analysis based on plate tectonic theory to the Abitibi Subprovince. Dimroth et al (1982;1983a,b) proposed that the Abitibi greenstone belt was formed as a magmatic arc built on tholeiitic and komatiitic oceanic lithosphere driven by a south verging subduction zone. The island arc was subsequently shortened in a north south compressional event, which led to production of granitic material. Termination of subduction is associated with rise of late tectonic batholiths.

Mueller et al. (1994; 1996; 1997) and Chown et al. (1992) propose a terrane-docking model based largely on the stratigraphy proposed by Dimroth et al. and facies associations of the Duparquet and Kirkland Lake sedimentary basins. The authors developed a four-stage model for development of the Abitibi. Massive volcanism accompanied arc formation (a 2730 - 2720 Ma) was followed by collision between a northern and southern arc around 2697-2690 Ma. This is thought to be the "docking" of the northern and southern volcanic zones along the PDDZ (Ludden et al., 1986). These arcs were later fragmented by transcurrent shear zones which coincided with Timiskaming sedimentation between 2689 and 2680 Ma. A final stage involves extension and uplift between 2660 and 2640 Ma.

Jensen and Langford (1985) invoked a stratigraphic or "fixest" model for formation of the Abitibi. In this model, large synclinoria formed from subsidence of large volcanic piles. Thus, the stratigraphy of the Abitibi was interpreted as a relatively continuous sequence of volcanic rocks deposited in repetitive cycles. The CLLDZ and the PDDZ were considered to be synvolcanic normal faults on the limbs of the large synclinoria. Later reactivation of these faults accommodated a relatively minor north south compressional event associated with the Kenoran orogeny.

Jackson and Fyon (1991) and Jackson et al. (1994) introduced the concept of lithotectonic assemblages. A lithotectonic assemblages is defined as a sequence of stratified volcanic and/or sedimentary rocks deposited during a discrete interval of time in a common depositional setting (Thurston

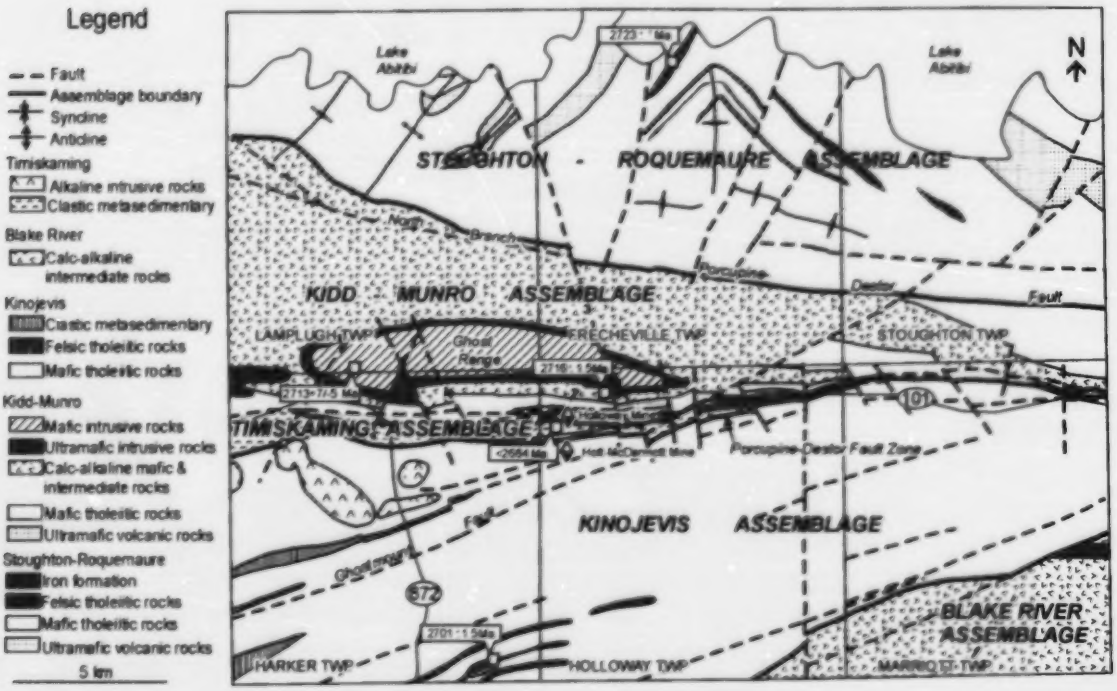

Figure 2.1: Regional geology of the Holloway area and location of the Holloway mine.

1991). Contacts between assemblages may be conformable, unconformable or tectonic and are marked by a change in depositional environment (Jackson et al.,1994). They hypothesized that more than one episode of subduction was required in order to generate the numerous assemblages in the Abitibi. This was made possible by microplate interactions driven by a number of subduction zones and corresponding faults.

New information obtained from the Swayze greenstone belt, now considered to be the western continuation of the Abitibi greenstone belt (Ayer et al.,1999, Heather et al.,1996), defines a relatively continuous stratigraphy. The existence of older, inherited zircons in younger volcanic rocks suggests that younger volcanics were emplaced directly on top of underlying units. This geochronological evidence shows this stratigraphy to be autochthonous and contemporaneous with the development of the Abitibi. These findings led to a new, Abitibi wide study initiated by Ayer et al. (1999) utilising and expanding upon existing geochronological and stratigraphic evidence.

Neither fixist nor dynamic models adequately account for all the geological evidence collected to date in the Abitibi. Fixist models have problems with the degree the metamorphism in the Abitibi. A volcanic pile ~ 35-40 km thick is required (Ayres and Thurston, 1985) which would lead to significantly higher metamorphic grades than are observed and subvertical isograds. Dynamic models fail if extended into the Ontario portion of the Abitibi where the stratigraphy can be traced across the PDDZ (Jensen and Langford, 1985; Brisbin, 1997, Ayer et al., 1999).

METAMORPHISM

The metamorphic grade throughout the Abitibi is greenschist to sub-greenschist grade, with amphibolite grade rocks encountered only within proximity to large plutons (Powell et al., 1993; Jolly, 1978).

In the Southern Abitibi, Powell et al. (1993) found peak metamorphic conditions to be between 250 - 270 °C and 2- 2.5 kbar, corresponding to a depth of 7 to 8 km. This conflicts with fixist stratigraphic models for the Abitibi which require volcanic piles ~ 35-40 km thick (Ayres and Thurston, 1985). Powell et al. (1993) indicated that regional metamorphic isograds are subhorizontal and cross-cut stratigraphy. Therefore, peak metamorphism must post-date tilting of the stratigraphy. Peak metamorphism in the area has been dated by Wong et al. (1991) to be 2684 ± 7 Ma. This corroborates the observations made by Powell et al. (1993), that peak metamorphism largely post-dates deposition of the major volcanic units which comprise the Abitibi (2750-2700) and is contemporaneous with known Timiskaming sedimentation. Subhorizontal regional isograds may have been displaced by vertical components of displacement about regional shear zones such as the Cadillac Larder Lake Deformation Zone. However, Powell et al (1993) found that a maximum of 1 km of reverse, south side up movement was plausible, given metamorphic gradients across the Cadillac Larder Lake Deformation Zone. Powell et al. (1993) also suggests that any reverse movement along major regional shear zones would have been penecontemporaneous with peak metamorphic conditions, based on pressure solution cleavages and carbonate minerals found within the deformation zones. The present study notes that massive volumes of carbonate rich fluid are required to produce the mineral assemblages found in the shear zones. The most likely source for these fluids was high - grade metamorphism in the middle to lower crust.

GEOLOGY OF THE HOLLOWAY MINE AND VICINITY

The Holloway mine is located within the PDDZ (Figure 2.1). The PDDZ is a zone of intense deformation and in the study area it is composed of structurally intercalated Keewatin volcanic rocks, assumed to be a minimum of 2700 Ma (Ayer et al., 1999) and unconformably overlain by Timiskaming sedimentary rocks, dated at 2684-86 Ma (Ayer et al., 1999). Keewatin rocks in this area are considered part of the Kidd Munro assemblage (Berger and Amelin, 1999). The PDDZ separates komatiitic, tholeiitic and calc-alkalic rocks of the Kidd - Munro assemblage to the north from dominantly tholeiitic rocks of the Kinojevis assemblage to the south. Given the geological setting of the Holloway Mine within the region, an overview of the Timiskaming, Kidd Munro and Kinojevis Assemblages is provided, emphasising field characteristics of the rocks.

Kidd - Munro Assemblage

The Kidd - Munro assemblage is comprised of komatiitic, tholeiitic and calc-alkalic volcanic rocks with minor intercalations of felsic flows and tuffs (Ayer et al., 1999). Kidd - Munro rocks are dated between 2717 and 2712 Ma (Corfu 1993, Bleeker and Parrish, 1996; Ayer et al. 1999). Originally thought to be restricted to the area between Kidd and Munro townships (Jackson and Fyon, 1991), the assemblage can now be extended from the Swayze greenstone belt in the west (Heather et al., 1996) to the Quebec border in the east (Berger and Amelin, 1999). One unit of particular interest is a variolitic marker unit, which can be traced from east of Matheson to the Holloway Mine area (Berger and Amelin, 1999).

Kinojevis Assemblage

The Kinojevis assemblages is comprised of a monotonous succession of pillowed, massive and flow brecciated tholeiitic volcanic rocks. Minor felsic flows are intercalated with the mafic rocks near the top of the assemblage and clastic sedimentary rocks are intercalated near the base. These units are upright and consistently dip and face south. These rocks likely form a continuous succession with the overlying calc-alkaline Blake River assemblage, and as such they record a transition from deep-marine to arc related volcanism (Ayer et al., 1999). The Kinojevis assemblage has been dated at 2701 ± 1 Ma (Berger and Amelin, 1999).

Timiskaming Assemblage

The Timiskaming assemblage is composed of polymictic conglomerates, sandstones and wackes that unconformably overlie Keewatin volcanic rocks of the Kidd - Munro, and Kinojevis assemblages in the study area. Timiskaming rocks have a distribution of ages between 2685 to 2675 Ma (Ayer et al., 1999; Corfu 1993). The Timiskaming assemblage is restricted to basins that are spatially related to regional shear zones (Thurston and Chivers, 1990; Mueller et al., 1994). Red jasper and alkali feldspar clasts are considered to be diagnostic features of Timiskaming rocks after the Kirkland Lake Basin (Hyde 1980). Timiskaming rocks have been interpreted, based on primary structures, as alluvial-fluvial sediments deposited in fault bounded pull-apart basins, in association with alkalic intrusive and extrusive volcanic rocks (Hyde, 1980; Thurston and Chivers, 1990; Mueller et al., 1991; Ayer et al., 1999). In the study area alkaline intrusions composed of syenite, albitite, hornblendite, and lamprophyre intruded the supracrustal rocks are part of the Timisakming assemblage (Berger and Amelin 1999).

THE PORCUPINE DESTOR DEFORMATION ZONE

Major regional shear zones such as the PDDZ and the CLLDZ play an integral role in the tectonic history of the Abitibi greenstone belt. A major focus of this study documented the relevant features of the PDDZ in the study area to better understand its role within a regional tectonic framework.

In the Abitibi, regional shear zones are linear features characterized by heterogeneous deformation, with discrete zones of intense deformation surrounding larger lithons of relatively undeformed rocks (Dimroth et al., 1982, 1983a, 1983b; Jensen and Langford, 1985; Smith et al., 1993; Wilkinson et al., 1999). The regional shear zones are commonly located on or near to the limbs of synclinoria and are commonly associated with Timiskaming sedimentary and alkaline igneous rocks (Jensen and Langford, 1985; Thurston and Chivers, 1990; Mueller et al., 1994). Early workers described the PDDZ as a synvolcanic normal fault that was reactivated in later north - south shortening events (Dimroth et al., 1982, 1983a, 1983b; Jensen and Langford, 1985). Jensen and Langford (1985) interpreted the regional shear zones as master normal faults on the limbs of subsidence-related synclinoria. Jackson et al. (1994) and Mueller et al. (1991, 1994) interpreted the PDDZ as a tectonic suture along which two allochtonous terranes were juxtaposed.

Neo-fixist models proposed by Heather et al. (1996) and Ayer et al. (1999) suggest that the regional shear-zones accommodated predominantly vertical movements as early as 2725 Ma. Subsequently Timiskaming sedimentation coincided with dip-slip movement, which was followed by small amounts of renewed vertical movement post deposition of Timiskaming rocks.

At present, there is no consensus on the role of the PDDZ within the regional tectonic picture. However, the regional shear zones are fundamental features with complicated, multiphase kinematic histories. A surprisingly small amount of study has been completed on the PDDZ, considering its crucial economic and tectonic significance.

GOLD MINERALIZATION IN THE ABITIBI

The prolific amount of gold within the Abitibi greenstone belt has made it the focus of debate on the origin of gold mineralization within Archean terranes. Two primary debates concern the timing of gold deposition, and the origin of mineralizing fluids. This section will provide an overview of the major types of gold deposits that have been identified in the Abitibi.

Four major types of gold deposits are recognized in the Abitibi. Robert and Poulsen (1997) identified three major types and Berger and Amelin (1999) have suggested a fourth. In order of the timing of development, these deposit types are synvolcanic and synsedimentary deposits, syenite - associated deposits, syntectonic mesothermal vein deposits, and remobilized post-tectonic vein deposits.

Synvolcanic deposits include VMS related gold deposits with ocean floor alteration and replacement facies, and are represented primarily by the Horne deposit in Quebec (Robert and Poulsen 1997). Synsedimentary deposition of gold is considered to be at least one important factor localizing gold in the Aunor and Dome deposits of the Timmins camp (Fryer et al., 1978). These early mineralizing events sparked interest in volcanic and sedimentary processes.

Syntectonic plutons, intruded near regional-scale shear zones became the focus of exploration and research due to their close spatial relationships with some gold deposits. Robert (1997) and Robert and Poulsen (1997) formalized a model in which mineralizing fluids are derived from the plutons during emplacement. Numerous examples of this type of deposit can be found in the Abitibi, including at least one phase of mineralization at the Aunor and Dome deposits (Fryer et al., 1978), as well as deposits associated with the Bourlamaque pluton of the Val D'Or district (Claoué-Long et al. 1990), the Kienna mine (Morasse et al. 1995), the Kerr-Addison deposit (Smith et al. 1993), the Hollinger McIntyre deposit (Burrows et al. 1986), the Holt McDermott deposit (Robert 1997) and the Holloway deposit (Guy 1996, Robert 1997).

Mesothermal syntectonic vein deposits are associated with carbonate-albite-tourmaline veins which cross-cut the regional foliation. The deposits are thought to have developed syntectonically, based on structural relationships, with deep crustal fluids that used the active shear zones as conduits, contemporaneous with orogenesis and peak metamorphism (Eisenlohr et al. 1989; Groves et al. 1997). Examples of such deposits include the Camflo Mine (Jemielitta et al., 1990; Corfu, 1993) and the Sigma mine (Robert and Brown, 1984; Wong et al., 1991).

A fourth, less common type of deposit, occurs as quartz veins with north-south strikes and moderate dips, and are thought to be due to a remobilization of gold bearing fluids along north-south fractures (Berger and Amelin 1999, Eisenlohr et al 1989). These deposits cross cut regional fabrics and formed late in the tectonic history of the area. The Croesus mine, perhaps the highest grade deposit in the Abitibi, is thought to be one such deposit (Berger personal communication).

Intimately intertwined with the debate on the timing of mineralization in the Abitibi, is the debate over the source of the mineralizing fluids. In the case of synvolcanic and syenite associated deposits the fluids were most likely derived from magmatic activity (Robert, 1997). For the syntectonic mesothermal vein deposits, fluids may have been metamorphic fluids from the deep crust. (Eisenlohr et al 1989,

Kerrich 1989, Jemielitta et al. 1990, Wong et al. 1991). The literature suggests that there were at least three phases of gold introduction into the Abitibi: synsedimentary and synvolcanic introduction of gold, followed by intrusion-related gold mineralization and a final metamorphism related mineralizing event.

Holloway Mine Stratigraphy

The Holloway mine is located within the PDDZ. The sequence of rocks which hosts the ore deposit has been tilted and folded into an east-west striking, south dipping package. Figure 3.1 is a geological map of the Holloway mine vicinity and a simplified cross section through the Holloway deposit is shown in Figure 3.2. The sequence is not part of a simple monocline, as early folding has resulted in repetition of several units (see Structural Geology Section). However, for ease of explanation, the rocks will be described beginning with the lowest structural position in the north and ending with the highest in the south. Two samples from the stratigraphy were sent for geochronological analysis at the Royal Ontario Museum. These dates are referred to in the following sections and will be published in the near future in the peer reviewed literature.

Figure 3.3 is a plan of the 415 - west sublevel showing the general stratigraphy of the deposit. Below the footwall contact, the ore zone is underlain by highly deformed and altered ultramafic volcanic rocks. The main ore zone, termed the "Lightning Zone", is hosted by a variolitic mafic hyaloclastite unit and is situated directly on top of the ultramafic rocks. In other locations, the ore zone is separated from the footwall ultramafic rocks by mafic volcanic, polymictic breccia or interflow sedimentary units.

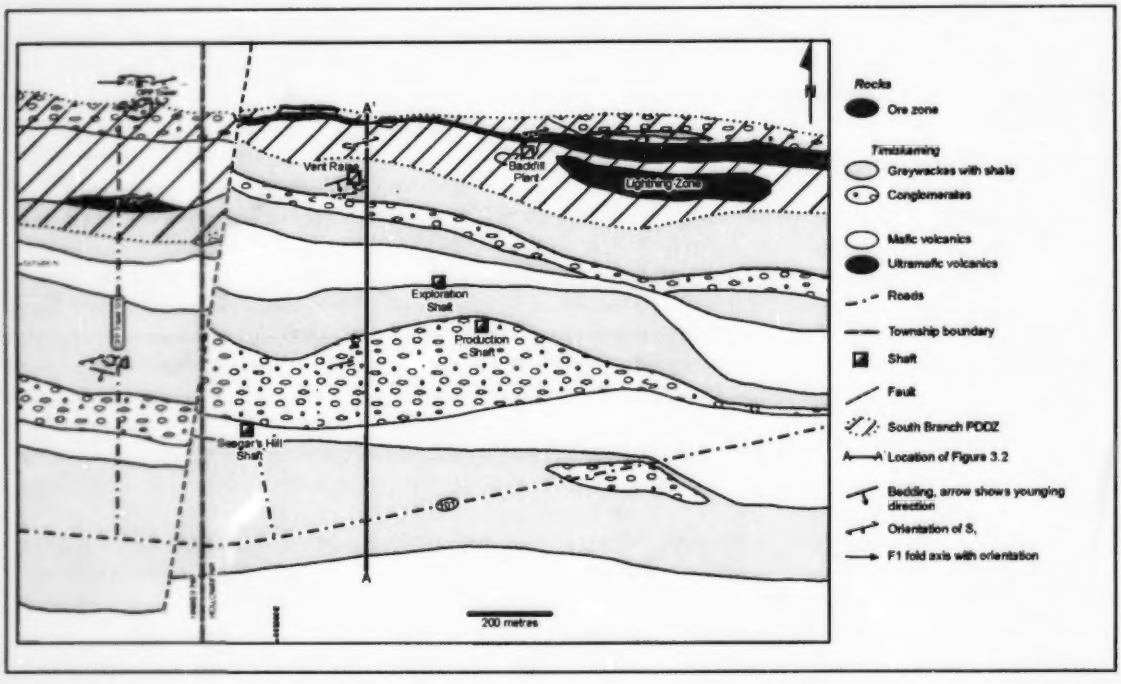

Figure 3.1. Geological map of the Holloway Mine area.

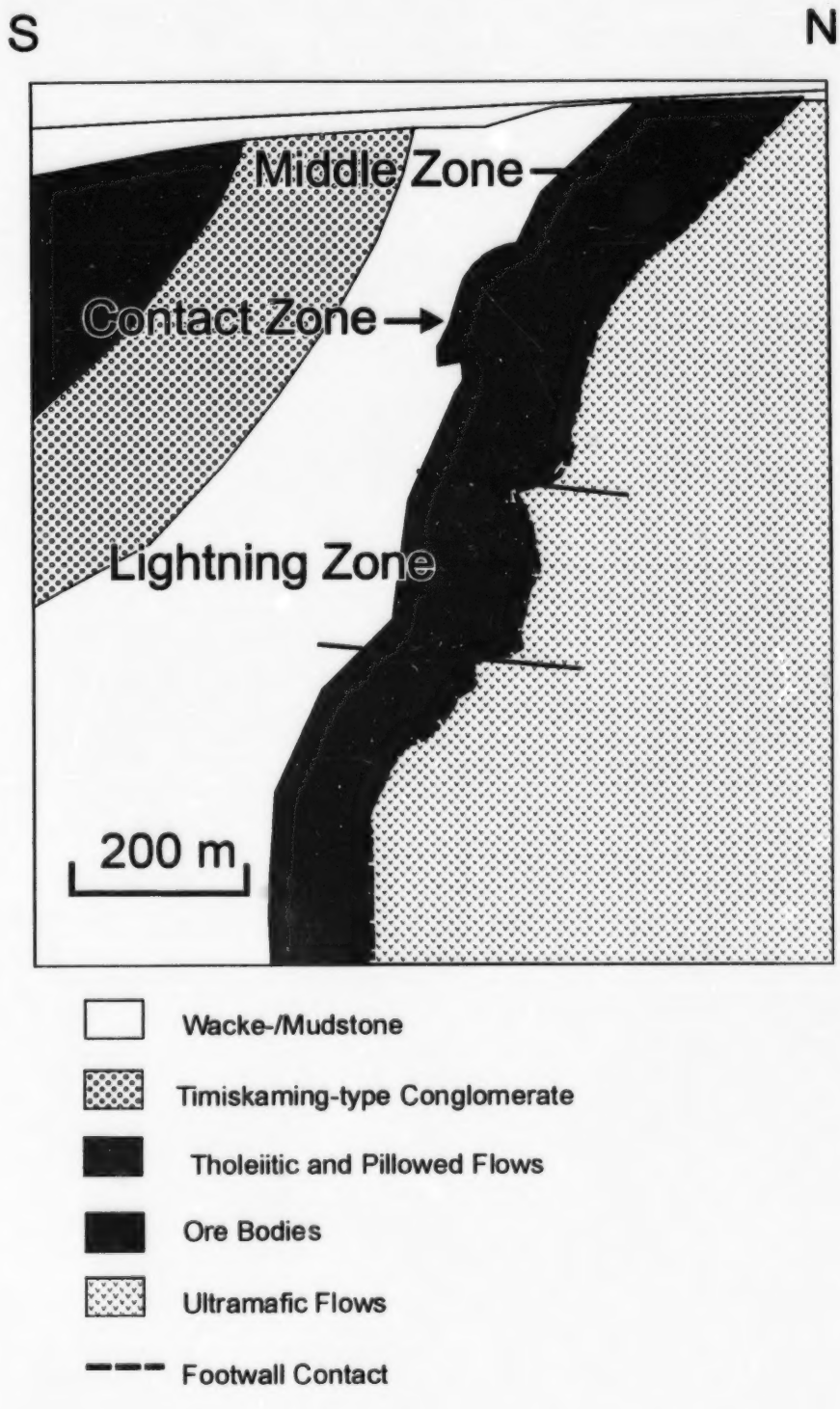

Figure 3.2: Simplified cross section looking west through the Holloway deposit.

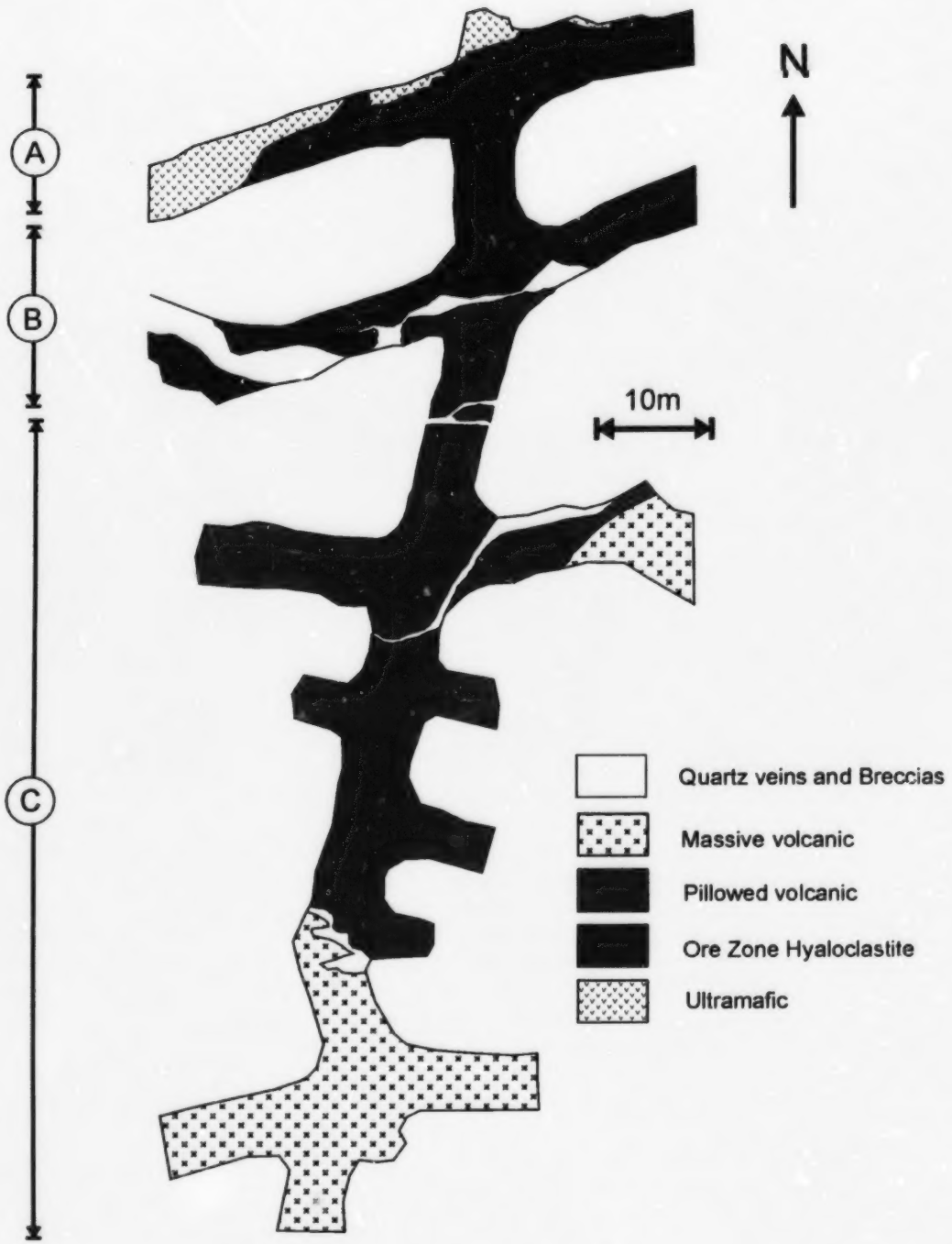

Figure 3.3. Plan of 415 west sublevel showing major lithologies and zones of differing Intensities of strain: A. Highly strained B. More competent lithon (low strain) and C. Highly strained.

Additional mineralisation occurs sporadically throughout the hangingwall sequence in "auxiliary" zones. The most prominent of these are the "Middle Zone", so termed as it is found in the middle of the lightning zone volcanic sequence, and the "Contact Zone", found at the contact between the lightning zone volcanic sequence and the overlying sedimentary rocks. Folded into and structurally overlying the ore zone is Timiskaming polymictic conglomerate. Pillowed and massive tholeiites, wackes and argillites and Timiskaming-type conglomerates and sandstones overlie the ore zone. In addition, interflow sediments (mostly argillites) are found between flows in the mafic volcanics most commonly at the footwall ultramafic mafic contact, and numerous mafic intermediate dykes cross-cut stratigraphy.

ULTRAMAFIC VOLCANIC ROCKS

The ultramafic volcanics are composed of about 60-70 % carbonate minerals, mostly calcite. Carbonate occurs as anhedral, very fine grained (<0.1 mm on average) grains with heavily altered crystal boundaries. Sericite and related fuchsite comprise an additional 20-25 % of the samples. Sericite is generally between 0.1 and 0.3 mm long and has anhedral habits, though the crystals are generally elongate. The remaining 5 % of the rock is composed of very small, equant, euhedral pyrite grains. Ultramafic footwall rocks are generally green and aphanitic, with porphyroblasts of bright green fuschite. The southern contact of this unit corresponds to a discrete zone of intense shear (the Footwall Contact Shear Zone (FCSZ)). Where not heavily carbonated, the rocks are talc chlorite schists. Locally, relics of original spinifex textures can be found indicating that these rocks are volcanic in origin.

Figure 3.4 shows the contact of the ultramafic rocks with overlying mafic volcanics in surface outcrop where the ultramafic volcanic rocks have weathered to a dull brown.

ORE ZONES

Lightning zone ore, which comprises 95 % of reserves in the Holloway mine, is distinctly translucent grey and weathers to a rusty reddish brown. The host rocks are extremely hard due to their large albite content. The ore zone is composed predominantly of albite, ranging from 60 to 95 %, along with variable amounts of carbonate (5 to 30 %) and pyrite (5-10 %). Variation of modal percentages is largely dependant on the amount of carbonate alteration the rocks have undergone. Albite is found as radiating, acicular grains that are generally 0.3 to 0.8 mm long and form varioles. Veins of albite are also observed within the ore zone and have large (up to 1 mm) euhedral albite grains displaying both polysynthetic and albite twinning. Carbonate minerals (calcite and/or ankerite) occur in two distinct modes, the first as small anhedral crystals throughout the groundmass and the second as what appear to be inclusions preferentially located around subgrains of albite. Pyrite also occurs in two modes in these rocks: 1) euhedral grains in the interstices between radiating albite grains (varioles) 2) as large , subhedral grains associated with sericite and carbonate veins.

Primary features include varioles and preserved hyaloclastite textures. Figure 3.5 shows a photomicrograph of the ore zone and preserved textures. Lightning Zone host rocks are predominantly mafic, variolitic hyaloclastite with minor amounts of massive and pillowed mafic volcanics that are entirely replaced with albite and later carbonate alteration.

Auxiliary zones, found within the hanging wall of the deposit, are often discontinuous and occur at all structural levels, most commonly at major lithological contacts. The two largest of these auxiliary

Figure 3.4: Contact between lightning zone related mafic volcanics to the left and footwall ultramafics to the right, looking west. Hammer for scale.

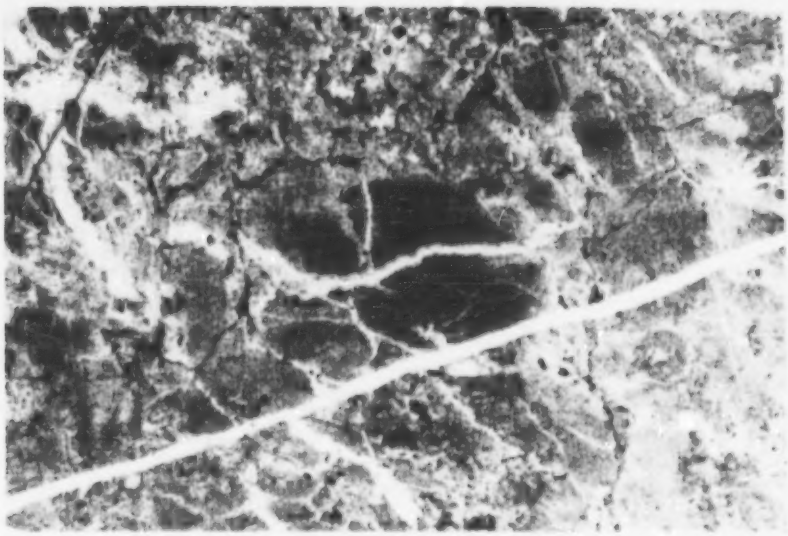

Figure 3.5. Photomicrograph taken from ore zone hyaloclastites showing preserved primary breccia textures. Field of view is 5mm.

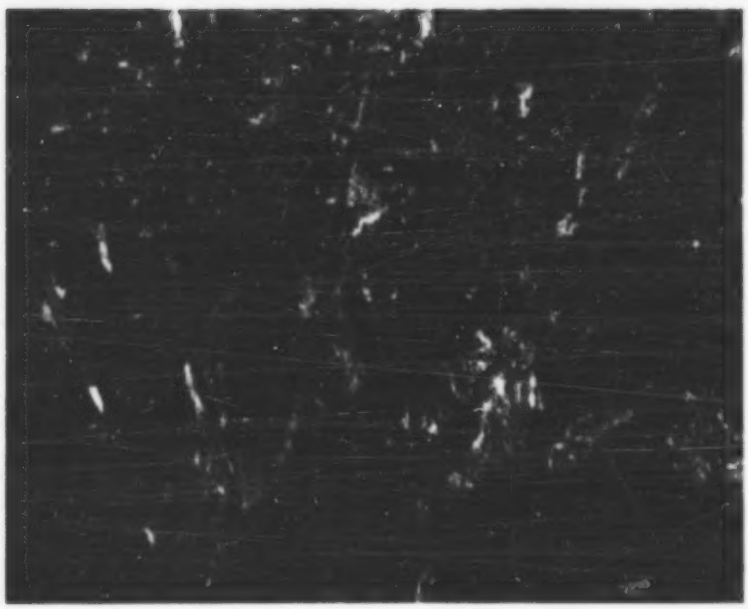

Figure 3.6. Highly strained pillows and pillow selvages, 415 sublevel. Metal plate is 15 cm.

zones are the Middle Zone, located at a flow contact within the Lightning Zone volcanic package, and the Contact Zone, located at the contact between the lightning zone volcanics and overlying sediments (See Fig. 3.2).

These zones are comprised of quartz veins and related sericite – carbonate alteration haloes, which have completely replaced original mineralogy of the host rocks. Rarely, weak albite alteration is associated with these zones. Within the quartz veins and haloes, pyrite is found as large (1 to 3 cm), euhedral grains. Only locally anomalous gold values are associated with these auxiliary zones.

PILLOWED BASALTS

Pillowed mafic volcanics are grey-green and have selvages of orange ankerite and dark green chlorite. The rocks are strongly deformed and are commonly carbonate-altered. Commonly, they are recognizable only by the presence of selvages, which yields a banded appearance. Figure 3.6 shows some less-strained pillows on the east face of 415 west level.

Pillowed mafic volcanics are composed of albite (40%), chlorite (35%) with variable amounts of carbonate (5 to 25 %), leucoxene (5 to 10%), sericite (5 to 10%) and pyrite (1 to 10%). The variations in composition are largely a function of alteration. Albite is found as small (<0.1 mm), subhedral groundmass laths and rarely as large (1 to 5 mm) euhedral phenocrysts. Chlorite occurs as anhedral grains throughout the groundmass, ranging in size from 1 to 3 mm as well as within pillow selvages. Small anhedral carbonate grains are found along grain contacts of original minerals. Sericite replaces large albite phenocrysts and as well, occurs in small veins which cross-cut the rocks. Leucoxene is found as 1 mm to 3mm linear agglomerates of opaque material totally replacing ilmenite. Subhedral to euhedral pyrite is restricted to haloes around cross-cutting carbonate veins.

Original ophitic textures, as well as the presence of pillow selvages suggest that these rocks are volcanic in origin and are albitized and carbonatized.

MASSIVE BASALTS

Petrographically, the massive mafic volcanics are identical in composition to their pillowed counterparts and are separated from them only by their larger grain size and lack of selvages. They have large amounts of albite as both microlaths and phenocrysts as well as large amounts of carbonate alteration. Leucoxene comprises a slightly larger percentage than found in pillowed rocks (10 to 20%), and appears to be pseudomorphic after titanite or ilmenite. Massive mafic volcanics are grey to black in colour with visible grains of bright yellow leucoxene forming a "speckled" texture as seen in Figure 3.7. The amount of leucoxene, larger overall grain size and the lack of pillow selvages distinguish these rocks from pillowed volcanics.

INTERFLOW ARGILLITES

Argillites are black, aphanitic and finely laminated (<1 cm), and are situated at all stratigraphic positions. They commonly form small lenses that are only rarely more than 5 m thick and 10 m in length. These rocks are only weakly cohesive and are fissile. Globules of framboidal, primary pyrite is often found within individual layers. The cryptocrystalline nature of these rocks makes ascertaining their

Figure 3.7. Deformed massive mafic volcanic with visible leucoxene and carbonate veining. 415 west sublevel.

mineralogical composition extremely difficult. They appear to be composed mostly of micaceous minerals with only a minor amount of very small (<1mm) grains of quartz and feldspar.

WACKE

Wacke are found as both interflow units and as larger, map scale units (See Map Back pocket). Wacke are light to dark grey, competent rocks which have beds between 1 and 10 cm in thickness. Graded bedding is common. Larger fragments of plagioclase are visible with the unaided eye. The matrix of the wacke is dominated by small (0.5 to 1 mm) plagioclase, carbonate and quartz grains, surrounding larger grains (1 to 4 mm) of plagioclase. Matrix minerals (quartz, plagioclase and carbonate) are uniformly rounded to subrounded. Larger feldspar clasts display microcline cross-hatch twinning and have angular, fragmented habits. Plagioclase in the matrix and as larger clasts has been variably sericitized.

CONGLOMERATES

Conglomerates in the mine sequence are commonly grey, with large, cobble sized, polymictic clasts. The matrix is made up of small (1-5 mm), well-rounded clasts of quartz and plagioclase and comprises between 40 and 95 % of the rock volume. Large well-rounded clasts range in size between 5 and 20 cm and are composed of albitized mafic rock, mafic volcanics, fuchsitic and chloritic ultramafic clasts, syenite, granodiorite, chert and jasper clasts. Accordingly, these rocks are considered to be of Timiskaming type (See Hyde, 1980). A sample of sandstone interbedded with the conglomerate was

dated and the U/Pb age of the youngest detrital zircon grains provides a maximum age for Timiskaming deposition of 2684 ± 1 Ma (Ayer et al 1999).

HETEROLITHIC BRECCIA

Found both within the ore zone (but not mineralized) and structurally above the ore zone is a heterolithic breccia. This breccia is composed of large, cobble sized mafic volcanic clasts including tholeiitic leucoxene-bearing and pillowed clasts within a fine grained matrix. Where unaltered, clasts are difficult to recognize and have the same colour and textures as the surrounding matrix, suggesting that they are similar in composition. The structural relationship with surrounding units is often difficult to ascertain. Early investigation by Guy (1996) suggested that this unit may cross-cut the stratigraphy, largely based on diamond drilling. Investigation carried out in this study suggests that this unit has been folded into and transposed along with the mine stratigraphy. A sample of this material was collected and processed for geochronological analysis and the youngest detrital population has an age of 2687 ± 2 Ma (to be published soon in the peer reviewed literature). This suggests that these are Timiskaming assemblage rocks, which have been folded into their present position within and above the ore zone, and that they possibly represent a basal member of the Timiskaming Group.

DYKES

Numerous dykes are found cross-cutting stratigraphy, including several intermineral dykes. The term intermineral is reserved for dykes that can be shown by structural relations to have been intruded between distinct episodes of alteration and mineralization (Kirkham, 1971; Morasse et al., 1995). The intermineral dykes are green, heavily carbonate altered and have rounded albite crystals, which are visible to the unaided eye. Large amounts of chlorite (up to 50 %) are found in these dykes in anhedral aggregates, likely replacing ferromagnesian minerals. The timing of these dykes relative to alteration and structural events is discussed in Section 6.1.

A sample of an intermineral dyke provided an U/Pb zircon crystallization age of 2671 ± 1.5 Ma. This age is important for constraining the timing of mineralization for the deposit, and is discussed in more detail in Chapter 6 of this report.

Structural Geology

The rocks underwent two major deformations in the Holloway mine. The main ore lenses of the Holloway deposit are enveloped by 080° striking, steeply south-dipping zones of intense deformation and fabric development. The ore lenses contain the same generations of structural fabrics as the surrounding rocks, and therefore they have undergone both deformations. The intensely deformed rocks that surround the ore lenses are characterized by a strong foliation and, locally, by an associated extension lineation. They are considered to be shear zones and they are, at least, tens of meters wide. The ore lenses represent lithons formed by boudinage of the more competent pervasively albitized mineralized zones within the surrounding rocks that are generally enriched in more ductile components (carbonate and sericite).

The zone of intensely deformed rocks that contains the ore-bearing lithons is considered to represent a main branch of the PDDZ, which, in the Holloway area, is made up of a system of shear zones that anastomose around the ore bearing lithons. This major branch of the PDDZ extends at least 250 meters to the south of the main ore zone, and for an unknown distance (at least 30 meters) north of it. Therefore, it

is determined that the PDDZ related shear zone in the area of the mine has a structural thickness of at least 280 meters.

D_1 STRUCTURES

Tight, isoclinal, steeply (85° to vertical) east-plunging F_1 folds are identified at the deposit scale. The folds are defined by repetition of lithological units in structural profiles (Fig. 4.1), and by documented reversals in facing directions that were determined using sedimentary structures (mainly graded bedding) that are preserved within the wacke.

A penetrative S_1 foliation is axial planar to the F_1 folds. Both S_0 (bedding in sedimentary rocks) and S_1 strike 080° and dip 75^0 to 90^0 to the south (Figs. 4.2 a, b). Small-scale, rootless intrafolial folds that are commonly observed within sedimentary rocks are also interpreted to be F_1 folds. The presence of intrafolial folds and the parallel orientations of bedding and S_1 suggest that the intense D_1 deformation resulted in complete transposition of the primary depositional structures parallel to S_1. The S_1 foliation is most strongly developed within the sheared rocks that are in immediate proximity to the hyaloclastites of the ore zone. S_1 is defined by the alignment of fuchsite and sericite crystals in ultramafic volcanic rocks. In the mafic volcanic rocks, S_1 is defined by the alignments of albite, calcite, chlorite and leucoxene crystals, and also by flattened pillows (Fig. 4.2 A). In the sedimentary rocks, S_1 is defined by the alignment of sericite and calcite crystals and by flattened clasts in conglomerate. S_1 is only locally preserved within the ore zone hyaloclastites, where it is mainly defined by stylolitic foliation bands, rich in opaque minerals (Fig. 4.3). S_1 is also found in dikes that cross-cut the ore zone, where it is defined by the alignment of calcite and sericite.

An L_1 extension lineation plunges down-dip on the S_1 foliation plane (Fig. 4.2 C), and is found in all lithological units in the mine. It is defined by stretched varioles in mafic volcanic rocks, and by stretched clasts in sedimentary rocks. L_1 is also defined by elongate minerals including leucoxene, albite and chlorite in mafic volcanic rocks, and by strain shadows, composed of fibrous quartz, that surround pyrite crystals within the ore zone (Fig. 4.4).

Asymmetrical microstructural features demonstrate that the D_1 event included non-coaxial strain within the PDDZ, at least within the Holloway deposit. The sense of shear associated with D_1 non-coaxial strain can be determined from microstructural observations made in oriented thin sections. Shear sense indicators, including asymmetrically folded extensional veins, displacement of dikelets within mesoscopic-scale shear zones and the strain shadows attached to pyrite crystals, all show a south side up, reverse sense of displacement associated with D_1.

D_2 STRUCTURES

All lithological units, primary depositional structures and D_1 structures are deformed into open F_2 folds that have subhorizontal axial planes (Fig. 3.2), and axes that plunge very shallowly to the east (Fig. 4.2 D). F_2 folds have half-wavelengths of approximately 150 meters. An S_2 foliation is axial planar to the F_2 folds and is most strongly developed within the hinge zones of the folds and on their sheared limbs. This S_2 foliation is a subhorizontal (Fig. 4.2 E), disjunctive pressure solution cleavage. Narrow cleavage bands with abundant opaque minerals that bound millimeter-scale microlithons that preserves the S1 foliation and primary bedding (Fig. 4.5) define S2. No extension lineation has been observed associated with S_2. The limbs of F_2 folds are often sheared and attenuated, resulting in a strong development of S_2, and offsets that displaces ore bodies on the order of tens of meters.

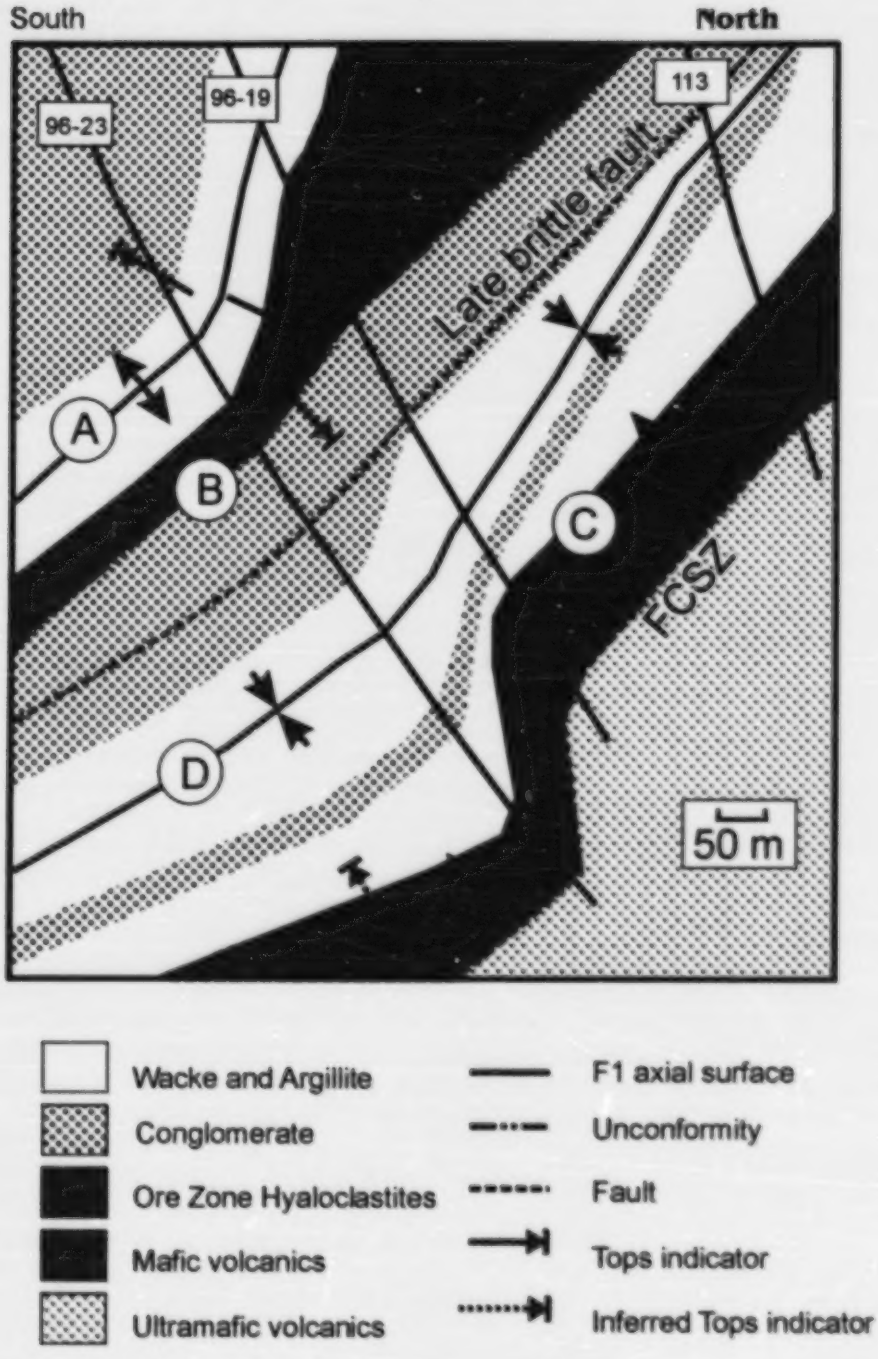

Figure 4.1. Structural Profile through the Holloway deposit looking West. Observed F1 folds are located at A, and interpreted at C and D. Tops are downhole at B.

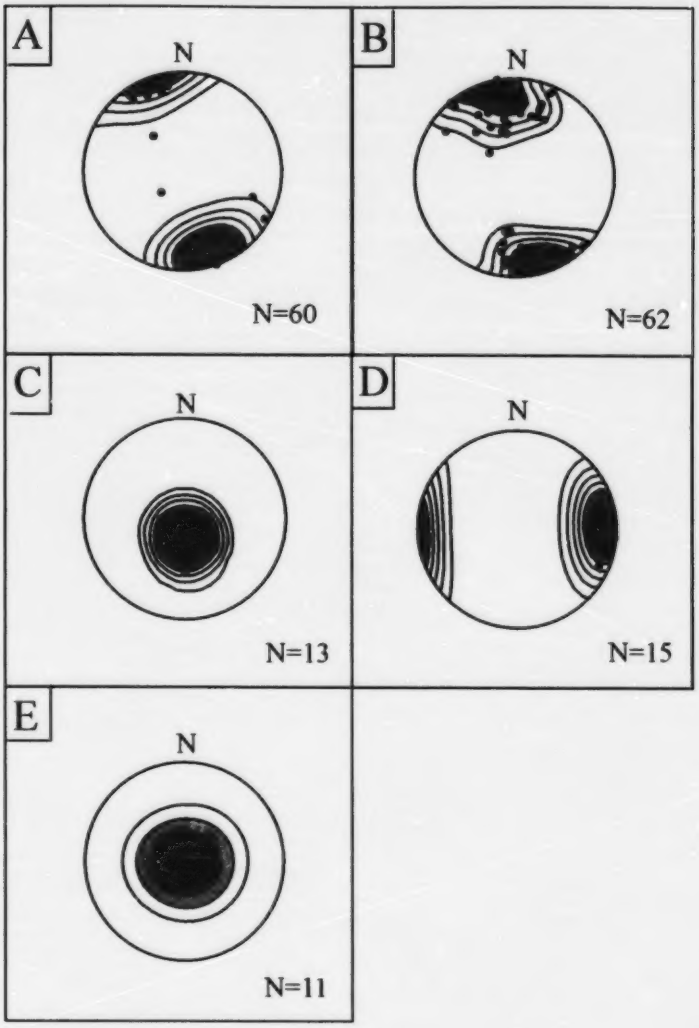

Figure 4.2. Equal area lower hemisphere projection showing major fabric elements of the Holloway deposit, including A) poles to S_0 B) poles to S_1 C) L_1 lineations D F_2 fold axes E) poles to S_2 crenulation cleavage..

Figure 4.3. S1 developed within the ore zone hyaloclastites. Field of view is 1 cm.

Figure 4.4. Strain shadow surrounding pyrite. Shear sense dextral. Field of view is 2 cm.

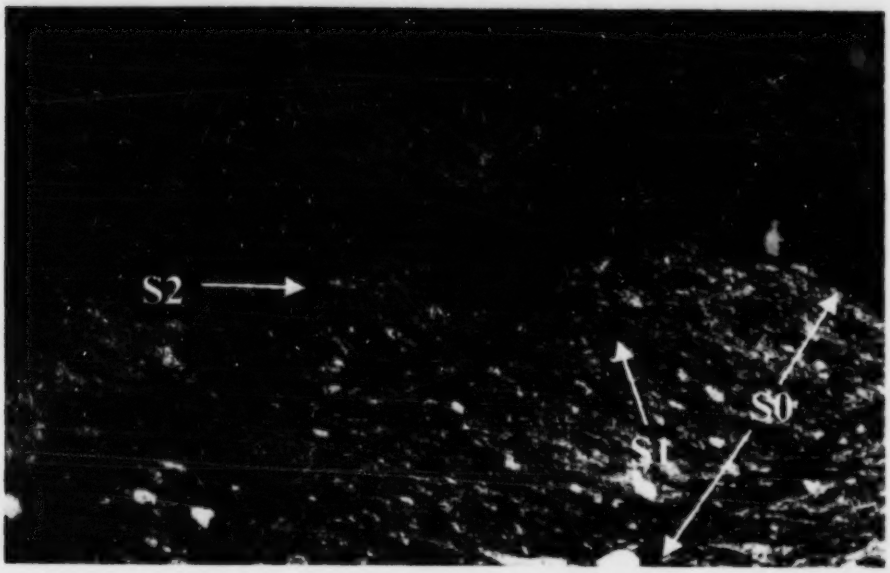

Figure 4.5. Photomicrograph showing relationship of So, S1 and S2. Field of view is 2cm. Taken from wacke, 520 west sublevel.

BRITTLE D_3, D_4 FAULTS

The deposit is cross-cut by a series of late brittle faults. The first set of brittle D_3 faults strikes 075° to 085°, and dips 75° to 85° south. Thin bands (approximately 10 cm) rich in chlorite and graphite define the faults. The D_3 faults have slickensides that indicate an almost horizontal, dextral strike-slip sense of displacement. A second set of brittle D_4 faults strikes north and is subvertical. Thin chloritic bands define the D4 faults and they consistently offset units with an east - side down sense of displacement. The relative ages of the two sets of brittle faults is not unequivocal, however, observations of drill core from holes spaced 25 to 50 meters apart suggest that the east–northeast striking D_3 faults are offset by the north striking D_4 faults.

Alteration

INTRODUCTION

All rocks within the Holloway deposit have been intensely altered. Describing the alteration, as well as determining the relative timing of alteration events is essential to further the understanding of the deposit. Primary observations of alteration underground and in drill core, followed by petrographic examination of the rocks were used to define the major alteration events associated with the deposit, as well as to

determine the relative and absolute timing of alteration events with respect to structures and mineralization. Cross-cutting relationships have constrained the relative timing of the major alteration events, and as such, the alterations will be described in order of oldest to youngest, followed by a brief discussion of mineralization.

EARLY CARBONATE ALTERATION

Carbonate alteration is ubiquitous in the deposit and overprints earlier primary mineral assemblages. In the field, carbonate alteration is manifested by a buff brown in mafic volcanic rocks, which weathers to a rust brown. In carbonated ultramafic rocks, still recognizable by the presence of spinifex textures, large amounts of fuchsite make the rocks a bright green, suggesting that there is a component of early potassic alteration (sericite) associated with the carbonate alteration. Sedimentary units tend to be a more yellowish brown when carbonatized. Carbonate veins are common in all carbonated rocks.

Petrographic examination of carbonated rocks reveals a large degree of replacement. In some units, upward of 50% of the modal volume is composed of calcite and smaller amounts of ankerite (5 to 10 %). Calcite grains, which effervesce in HCL, have anhedral forms, occur as small grains (<1mm) and fill interstitial spaces throughout the rocks. In mafic volcanics small calcite grains pseudomorph feldspars. Likewise, in sedimentary units, calcite replaces feldspar clasts and occupies interstitial spaces. In ultramafic volcanic rocks, the alteration is more pervasive, and nearly complete replacement of original minerals has occurred. Very fine grained calcite and associated fuchsite make up to 80% of ultramafic rocks, with only minor amounts of chlorite and amphiboles, suggesting that these ultramafic volcanics have no primary mineralogy intact.

Carbonate alteration is cross-cut by, and cross-cuts all other types of alteration within the mine sequence. This suggests that carbonate alteration started early in the history of the deposit, and either continued over a long period of time, or represents a number of discrete events. The general similarity in alteration styles of all carbonated rocks favours a single, long-lived alteration event.

HEMATITE ALTERATION

Patchy hematite alteration is found within and outside of the main ore zone as a replacement of previously carbonatized rocks. It is of particular interest to this study, as it often corresponds with lower gold grades within the ore zone. Hematite occurs as a pervasive alteration that adds a deep purple hue to volcanic rocks, and a reddish brown hue to sedimentary units. In thin section, the alteration exists as rims of hematite around minerals such as calcite and amphibole. All rocks that are hematized have been previously carbonatized. Very fine grained, aphanitic and amorphous specular hematite fills interstitial spaces and appears to be the insoluble remnants of an iron rich, oxidizing fluid.

The distribution of hematite alteration is irregular and inherently unpredictable. Areas of intense hematite alteration are best described as patches, within previously carbonatized rocks. Where rocks have undergone subsequent alteration, the hematite alteration may be obscured. Later albitization and carbonatizaton can be seen cross-cutting and invading hematized rocks.

ALBITE ALTERATION

Albite alteration is typically spatially associated with gold mineralization within the Holloway deposit. There are two major types of albite alteration. An early, pervasive alteration (Ab 1) involves complete

replacement of previously carbonatized and hematized rock with albite. A second albitization event (Ab 2) is characterised by small veinlets of albite and carbonate which cross cut the earlier albite alteration. Ab 1 involves a more pervasive style of alteration while Ab 2 is vein related. However, these alteration events share both mineralogy and timing relationships and are therefore considered coeval.

Pervasively albitized rocks (Ab 1) are completely replaced by albite and are predominantly hyaloclastites, although massive mafics are less commonly pervasively albitized. These units are light grey to light brown, and are extremely hard. They are comprised of almost 90 % albite, with only accessory pyrite, quartz and some late carbonate alteration occupying interstitial spaces. Relics of primary breccia textures can be seen (Fig. 3.5). Albite forms interlocking clusters of radiating crystals, unique to this style of alteration. An example of this unique texture can be found in Figure 5.1, taken from an albitized hyaloclastite from 520 -west sublevel.

Small albite microveinlets (Ab 2), less than 1 mm in thickness are found cross-cutting the Ab 1 altered rocks. These veinlets contain large (up to 1 mm) crystals of albite and small amounts of calcite.

Albite alteration is predominantly found in ore zone hyaloclastite and is only locally found in other lithologies. However, the albite alteration is not confined to this horizon. Several smaller zones of pervasively albitized rocks have been observed in the hangingwall of the deposit.

LATE CARBONATE AND SERICITE ALTERATION

Small (1 to 5 cm thick) carbonate veins are found within and proximal to D2 fold hinges and faults. These veins cross-cut previously carbonated, hematized and albitized rocks. Enveloping these veins are halos of sericite and carbonate alteration (Sr). Veins have flat to moderately dipping orientations with alteration haloes approximately three times that of the vein's thickness. The veins themselves are typically composed of calcite, ankerite and sericite while halos are composed of mostly carbonate and sericite, as well as small amounts of pyrite. Haloes in mafic volcanic and sedimentary rocks are buff brown, whereas, in ultramafic rocks they have a distinct bright green.

Figure 5.2 shows this late alteration surrounding carbonate veins and crosscutting metamorphosed and hematized volcanics. Elevated arsenic and rare economic gold mineralisation is associated with this alteration and may comprise some of the auxiliary zones within the hanging wall of the deposit.

GOLD MINERALIZATION

Gold mineralization within the Holloway deposit is spatially associated with pyrite and albite alteration. Modal pyrite percentages are used by the mine geologists to accurately estimate gold values. In addition to pyrite, tetrahedrite, chalcopyrite, arsenopyrite, molybdenite and native gold are all found within the deposit in trace amounts.

Pyrite occurs in two crystal habits, each coeval with a particular alteration style. The first major habit of pyrite (Py 1) occurs as small (0.1 - 0.5) mm, euhedral crystals, spatially confined within albitized (Ab 1 and Ab 2) rocks. Py 1 commonly occupies interstitial spaces between radial albite clusters as well

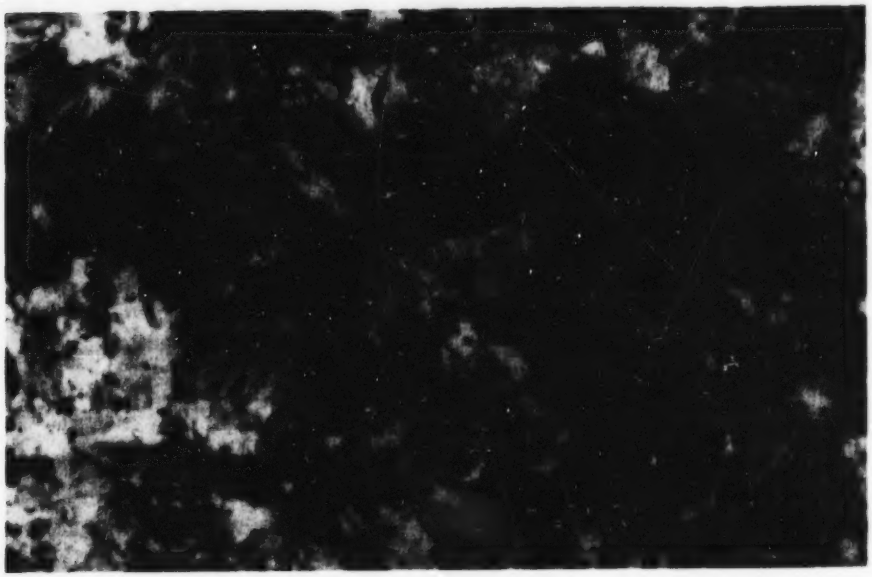

Figure 5.1. Radiating albite crystals associated with Ab 1 alteration. Field of view is 5mm.

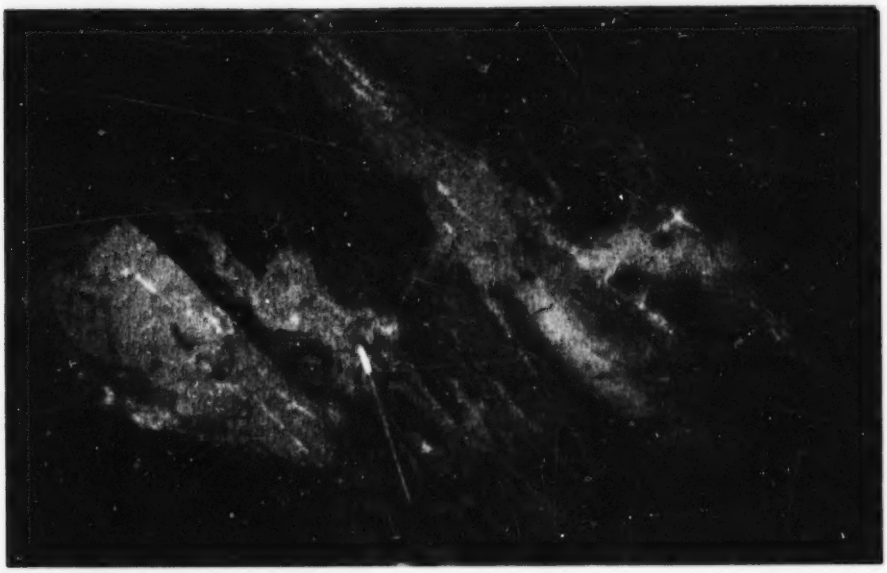

Figure 5.2. Sericite/carbonate haloes surround carbonate veins. 505 west sublevel. Marker is approximately 15 cm long.

as between minerals within Ab 2 veinlets. Volume percentage of Py 1 rarely exceeds 5%, and is found exclusively within the albitized host rocks of the ore zone.

The second crystal habit of pyrite (Py 2) is found within the haloes of the sericite-carbonate vein (Sr) alteration. These pyrites range in size from 0.5 to 2 cm and are subhedral to euhedral. They are commonly found in greater volumes closest to the sericite-carbonate veins and can reach volume percentages of 25-30 % locally. These pyrites are also associated with anomalously high gold grades in the deposit. High concentrations of arsenic are also common within rocks that contain large percentages of Py 2. Py 2 is found throughout the deposit, within, as well as outside of, the ore zones.

The albite (Ab 1 and Ab 2) and late carbonate/sericite (Sr) alteration events are temporally distinct. A separate pyrite and gold mineralizing event is associated with each of these alteration events. This indicates that there are at least two, temporally distinct gold mineralizing events in the Holloway deposit. The first associated with albite alteration and Py 1 pyrite mineralization, and the second associated with the carbonate/sericite (Sr) alteration and Py 2 mineralization. The relative importance of the two mineralizing events has not yet been determined. However, the spatial distribution of gold grades associated with the two mineralizing events suggests that gold was introduced by the earlier, pervasive (Py 1) event and subsequently remobilized during Py 2 mineralization.

Synthesis

TIMING OF ALTERATION AND MINERALISATION

An intensely deformed, intermineral dyke cross-cuts albitized ore zone rocks. This dyke has a well-developed S1 foliation and provides a reference to which the relative and absolute timing of alteration and mineralization can be compared. Figure 6.1 shows a photograph taken underground at the 505 east sublevel of the dyke where it cross-cuts albitized and mineralized rocks. A sample of this dyke was sent for U/Pb zircon geochronological analysis at the Jack Satterly Laboratory, Royal Ontario Museum, Toronto. A crystallization age of 2671 ± 1.5 Ma was obtained (Y. Amelin, personal communication).

Figure 6.2 shows the relative and absolute timing of the alteration, mineralization and deformation events. Carbonate (Co3) and hematite (Hm) alteration clearly predate intrusion of this dyke. The dyke also cross-cuts both albitized (Ab 1 and Ab 2) and mineralized (Py 1) hyaloclastites, providing a minimum age of mineralization for Py 1. Py 2 mineralization, as well as the later carbonate and sericite (Sr) alteration cross cut and therefore postdate intrusion of the dyke. Figure 6.3 shows a late sericitic vein cross cutting previously albitized and carbonated rocks. Thus, a minimum age for hematization, albitization and mineralization and a maximum age for D1 deformation is established by the intermineral dyke, intruded at 2671 ± 1.5 Ma.

THE PDDZ

The PDDZ is a zone of intense, heterogeneous strain. Discrete zones of intense strain (shear zones) surround relatively undeformed lithons. F1 folding, identified on the basis of numerous facing reversals in the stratigraphy, was a key mechanism in accommodating shortening during the development of the PDDZ during D1. It is important to note that no evidence of significant strike-slip displacement was

Figure 6.1. Intensely deformed intermineral dyke seen cross cutting albitized and mineralized hyaloclastites. 505 east sublevel.

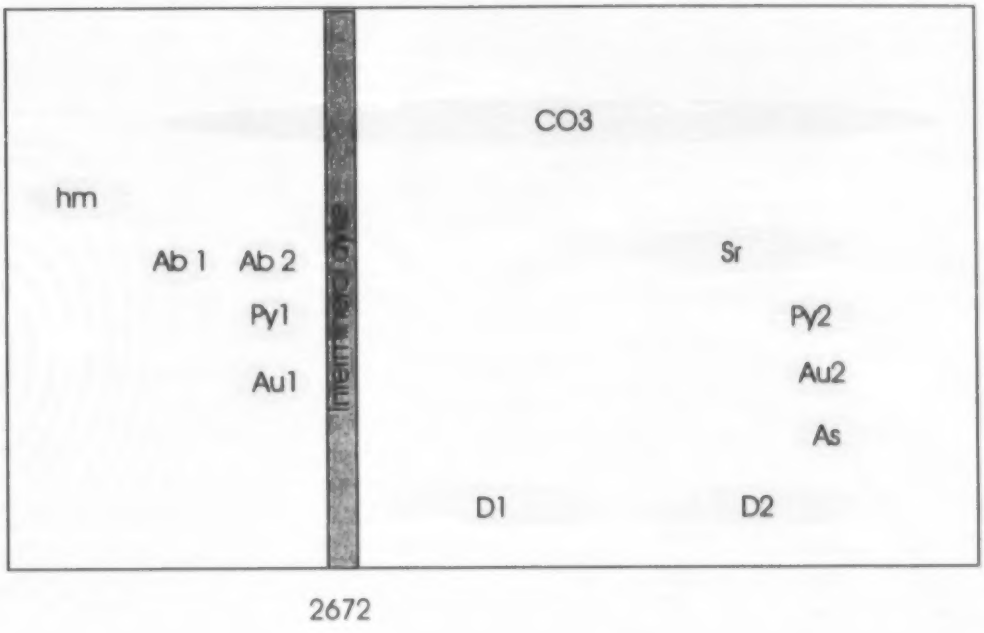

Figure 6.2: Diagram showing timing relationship of alteration and mineralization events with respect to the principal structures. Hm - hematite; Co3 - pervasive carbonate; Ab - albite; Py - pyrite mineralization, Sr - Sericite/carbonate; Au - gold mineralization; As - Arsenic; D - deformation events.

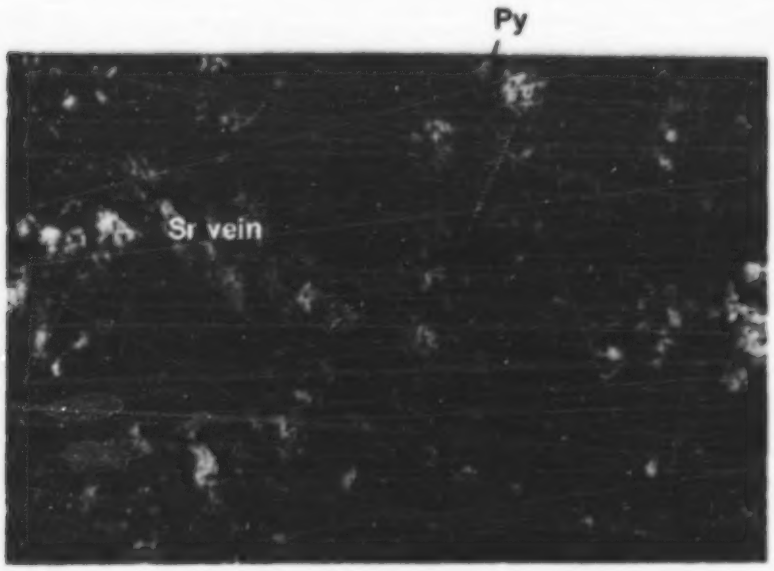

Figure 6.3. Photomicrograph showing small Sr vein cross cutting albitized and carbonated hyaloclastite. Field of view is 2cm.

identified; rather, kinematic indicators associated with steeply plunging extension lineations record a south-over-north reverse sense of shear on the PDDZ.

Carbonate alteration played an important role in deformation along the PDDZ. Intense deformation is universally accompanied by large amounts of carbonate alteration and replacement. These fluids are likely products of high grade metamorphism of the mid to lower crust (Fyon et al., 1988; Powell et al., 1993). This suggests that the PDDZ is a crustal scale feature along which fluids have migrated. This corresponds with Jackson et al. (1994), who interpreted the PDDZ to extend to a minimum 10 km thickness using deep seismic data.

Another diagnostic characteristic of the PDDZ is the presence of Timiskaming sedimentary rocks. The compositions of clasts within the Timiskaming rocks imply proximal provenance, supporting previous interpretations that the rocks were deposited in restricted, fault bounded basins (Hyde 1980, Thurston and Chivers 1990, Mueller et al., 1994). Deposition of the Timiskaming assemblage in basins that were controlled by the PDDZ, in conjunction with the fact that the Timiskaming assemblage has been strongly deformed during the D1 event indicates that the PDDZ existed, in some form, prior to D1. The PDDZ may have existed as a crustal scale normal fault along which mineralizing fluids (metamorphic or intrusion related) would have migrated up through the crust and metasomatized areas of high permeability.

GEOLOGICAL HISTORY OF THE HOLLOWAY MINE

The objectives of this project were to define and describe all structures within the Holloway deposit in order to document any structural controls on gold mineralization, while also providing new insights into the deformation style and tectonic implications of the PDDZ in this area.

The host rocks of the mine are assigned to the Kidd Munro assemblage, and as such were extruded in an ocean floor environment between 2717 and 2712 Ma (Jackson and Fyon, 1991; Ayer et al., 1999). Rocks of the Kinojevis assemblage were also deposited in an oceanic floor environment between 2701 and 2698 Ma, but the contact between Kidd Munro and Kinojevis rocks is delineated by the PDDZ and is poorly understood (Ayer et al., 1999).

Prior to, or during the development of D1 structures, the Ab1, Ab2, Hm and early CO3 alteration and gold mineralization accompanied alkalic igneous activity. It was also during this period that deposition of Timiskaming sedimentary rocks took place. Based on the age of the cross cutting intermineral dyke and the Timiskaming conglomerate, these events occurred between 2684 ± 1 Ma and 2671 ± 1.5 Ma.

The D1 structural event on the PDDZ that is characterized by east–west F1 isoclinal folding and strong S1 development occurred during a regional north–south shortening. As the S1 fabric is preserved within the intermineral dyke, 2671 +- 1.5 Ma is the maximum age for the end of the D1 event. D1 deformation resulted in the folding of ore bearing zones, and the formation of the discrete zones of intense S1 and L1 development (shear zones) that surround the more competent ore bearing lithons.

The tectonic origin of the subhorizontal D2 structures is, at present, not completely understood. One possible explanation for the formation of the shallowly dipping F2 folds and S2 cleavage would be continued north-south shortening, and further south-over-north displacement on the PDDZ, following the development of the strong, pervasive D1 fabrics. This may have resulted in the development of the kink-like F2 folds due to differential displacement rates within the PDDZ. Differential displacement rates could have resulted, at least in part, from the presence of the mechanical anisotropies within the PDDZ, that would be represented by the relatively rigid, ore bearing lithons.

CONCLUSIONS

In the study area, the PDDZ is defined as a zone of heterogeneous strain, with discrete zones of intense deformation surrounding lithons of relatively undeformed rocks. The zone itself can be traced across a width of 250 metres south of the footwall contact of the Holloway deposit, and is open to the north of this contact. Deformation within the PDDZ included D1 folding and south-over-north displacements within the zones of intense shearing, and intense carbonate alteration. The formation of later F2 folds and S2 crenulations may have been related to late stages of north-south shortening. The Timiskaming sedimentary rocks are spatially associated with the PDDZ.

A minimum age of 2671 ± 1.5 Ma is established for the primary gold mineralization within the Holloway deposit, which predates, or was synchronous with, S1 development. A second gold mineralizing event post-dates both intrusion of the dyke and the earlier gold mineralization. Mineralization is intimately associated with pyrite mineralization and albitization, and is confined to the PDDZ which, judging by the extent of alteration within the deformation zone, was likely the primary conduit for the huge volumes of mineralizing fluids.

Recommendations for Prospectors

The recommendations for prospectors are provided in two sections. The first (7.1) is a section intended for exploration at the deposit scale. The second is intended for regional-scale exploration.

DEPOSIT SCALE RECOMMENDATIONS

Mine site exploration has been hampered by the lack of geometric predictability of ore zones. The intense deformation, including folding at all scales and later brittle faulting makes extrapolation of existing ore boundaries difficult. The unpredictability and relatively inconsistent gold grades and distribution of alteration have required closely spaced definition drilling, and geological control underground.

Several observations may prove helpful in deposit scale exploration surveys. First, the ore zones are consistently found as competent lithons within shear zones consisting of the most intensely strained rocks. This strain can be identified by the transposition of primary structures such as bedding and pillow selvages, well developed foliations defined by alignment of minerals, and an increase in carbonate alteration. Second, ore zones are discontinuous and pinch off as boudin structures oriented parallel to, and within the PDDZ. There is a consistent spacing of between 400 and 500 metres between the centres of these boudinaged lenses. Third, the ore zone is not confined to a specific stratigraphic horizon, in fact, several smaller lenses of albitized and mineralised zones have been folded into different structural levels.

Brittle faulting has also affected the geometry of ore bodies. East trending faults tend to show a dextral strike-slip sense of movement. North-south striking faults show east-side down movement. Subhorizontal faulting, associated with D2 folding, commonly shows conjugate movement, exaggerating the effects of the D2 folds such that the hinge zones of these folds are often pushed out (to the south).

Continued exploration both south and north of known mineralization is recommended. In addition, exploration along strike of the deposit within the PDDZ could reveal additional lenses of ore grade material. However, care should be taken not to focus exclusively on any single stratigraphic contact, as ore grade material can be found at multiple structural levels.

REGIONAL SCALE RECOMMENDATIONS

Holloway represents a deposit that is located within a major shear zone. Other deposits that share this geometry are the Kerr Addison deposit in the CLLDZ (Smith et al., 1993), in the Virginiatown area, the Taylor deposit and the Glimmer deposit in the PDDZ west of the study area (Berger 1999, 2000). Previous exploration initiatives have concentrated on second order splays of major regional shear zones. However, the present study shows that significant potential lie within the regional shear zones themselves.

The PDDZ and other regional shear zones can be recognized by their intense fabric development, indicative of ductile deformation. Accompanying this intense deformation is pervasive carbonate alteration. Later, brittle faults have sometimes been confused with these regional deformation zones. Brittle faulting has played an important role in modifying previously existing ore deposits. However, recognition of early ductile "shear zones" is crucial as they are the primary structural controls on mineralization of the Holloway mine type.

Any regional-scale exploration program should attempt to define and delineate these shear zones as a primary goal. Once the shear zones have been delineated, exploration should concentrate towards favourable albitic or sericitic alteration packages. Furthermore, continued studies of the nature of the PDDZ should be continued along strike. The kinematics, displacements and geometry of the PDDZ may conceivably change along strike, necessitating the development of modified geometrical models for other, as yet undiscovered deposits.

References

Ayer, J.A., Trowell, N.F., Amelin, Y., and Corfu, F., 1999. Geological Compilation of the Abitibi Greenstone Belt I Ontario: Toward a revised stratigraphy based on compilation and new geochronology results; in Summary of Field Work and Other Activities 1998, Ontario Geological Survey, Miscellaneous Paper 169, p.14-24.

Berger, B. R., Luinstra, B. L. and Ropchan, J. C., 2000. Precambrian geology of the Ghost Range area; Ontario Geological Survey, Map 2563, scale 1:50 000.

Berger, B. R., 1999. Geological investigations along Highway 101, Hislop Township in Summary of field work and other activities 1999; Ontario Geological Survey, Open File Report 6000, section 5-1 to 5-8.

Berger, B.R., 2000. Geology of the Monteith area; Ontario Geological Survey, Open File Report 6024, 77 p.

Berger, B. and Amelin, Y., 1998. Geological investigations along Highway 101; Guibord, Michaud and Garrison townships, in Summary of field work and other activities 1998, Ontario Geological Survey, Miscellaneous Paper 169, p. 25-32.

Bleeker, W. and Parrish, R.R., 1996. Stratigraphy and U-Pb zircon geochronology of Kidd Creek: implications for the formation of giant volcanogenic massive sulphide deposits and the tectonic history of the Abitibi greenstone belt: Canadian Journal of Earth Sciences, v.33, p. 1213-1231.

Brisbin, D.I., 1997. Geological setting of gold deposits in the porcupine gold camp, Timmins, Ontario. Ph.D thesis, Queens University, Kingston, Ontario, Canada, 523 p.

Broughton, D., Green, K. and Cooper, P., 1991. Geology of the Holloway Project. Volume 1 technical report. Hemlo Gold/Freewest Joint venture, Holloway township, Ontario.

Burrows, D.R. and Spooner, E.T.C., 1986. The McIntyre Cu-Au deposit, Timmins, Ontario, Canada. In: MacDonald A.J., ed., Gold '86. Willowdale, Ontario, Konsult International., p.23-39.

Chown, E.H., Daigneault, R., Mueller, W., and Mortensen, J., 1992. Tectonic evolution of the Northern Volcanic Zone, Abitibi Belt, Quebec. Canadian Journal of Earth Sciences. V.29, p.2211-2225.

Claoue-Long, J.C., King, R.W., and Kerrich, R., 1990. Archean hydrothermal zircon in the Abitibi greenstone belt: constraints on the timing of gold mineralization. Earth and Planetary Science Letters, v. 98, p.109-128.

Cooper, P., 1994. Geology of the Holloway Joint Venture, Lightning Zone, Hemlo Gold Mines Inc.; A presentation to the Toronto Geological Discussion Group, Toronto, Ontario, 17 p.

Corfu, F., 1993. The Evolution of the Southern Abitibi Greenstone Belt in Light of Precise U-Pb Geochronology; Economic Geology, v. 88, p. 1323-1340.

Dimroth, E., Imreh, L., Goulet, N. and Rocheleau, M., 1982. Evolution of the south-central segment of the archean Abitibi Belt, Quebec. Part I: stratigraphy and paleogeographic model. Canadian Journal of Earth Sciences, v.19, p.1729-1258.

Dimroth, E., Imreh, L., Goulet, N. and Rocheleau, M., 1983a. Evolution of the south-central segment of the archean Abitibi Belt, Quebec. Part II: Tectonic evolution and geomechanical model. Canadian Journal of Earth Sciences, v.20, p.1355-1373.

Dimroth, E., Imreh, L., Goulet, N. and Rocheleau, M., 1983b. Evolution of the south-central segment of the archean Abitibi Belt, Quebec. Part III: Plutonic and metamorphic evolution and geotectonic model. Canadian Journal of Earth Sciences, v.20, p.1374-1388.

Eisenlohr, B.N., Groves, D. and Partington, G.A., 1989. Crustal-scale shear zones and their significance to Archaean gold mineralization in Western Australia; Mineralium Deposita, v.24, p.1-8.

Fryer, B.J., Kerrich, R., Hutchinson, R.W., Pierce, M.G. and Rogers, D.S., 1978. Archaean precious-metal hydrothermal systems, Dome Mine, Abitibi Greenstone Belt. I. Patterns of alteration and metal distribution. Canadian Journal of Earth Sciences, v.16, p. 421-439.

Groves, D.I., Phillips, N., Ho, S.E., Houstoun, S.M. and Standing, C.A., 1987. Craton scale distribution of archean greenstone gold deposits: Predictive capacity of the Metamorphic model; Economic Geology, v.82, p.2045-2058.

Guy, R., 1996. The geology of the Holloway Deposit, Abitibi greenstone belt, Ontario. M.Sc. Thesis, Queens University, Kingston, Ontario, Canada, 184 p.

Heather, K.B., Shore, G.T. and van Breemen, O. 1996. Geological investigations in the Swayze greenstone belt, southern Superior Province, Ontario; a final update; in Geological Survey of Canada, Current Research Paper1996-1C, p.125-136.

Hyde, R.S. 1980. Sedimentary facies in the Archean Timiskaming Group and their tectonic implications, Abitibi greenstone belt, northeastern Ontario, Canada. Precambrian Res., 12: 161-195.

Jackson, S.L. and Fyon, J.A., 1991. The Western Abitibi Subprovince of Ontario; in Geology of Ontario, Ontario Geological Survey, Special Publication 4 part 1, p.405-484.

Jackson, S.L., Fyon, A.J. and Corfu, F. 1994. Review of Archean supracrustal assemblages of the southern Abitibi greenstone belt in Ontario, Canada: products of microplate interaction within a large-scale plate-tectonic setting; Precambrian Research, v.65, p.183-205.

Jemielita, R. A., Davis, D.W., Krogh, T.E., and Spooner, E.T.C., 1990. U-Pb evidence for Abitibi gold mineralization postdating greenstone magmatism and metamorphism; Nature, v. 346, p.831-834.

Jensen, L.S., and Langford, F.F., 1985. Geology and petrogenesis of the Archean Abitibi Belt in the Kirkland Lake Area, Ontario; Ontario Geological Survey, Miscellaneous Paper 123, 130 p.

Kerrich, R., 1989. Archean Gold: Relation to granulite formation or felsic intrusions?; Geology, v.17, p. 1011-1015.

Knight, C.W., Burrows, A.G., Hopkins, P.E., Parsons, A.L., 1919. Abitibi-NightHawk gold area, District of Timiskaming, Ontario Bureau of Mines, v.28, 1919, pt 2, p. 1-70.

Ludden, J., Hubert, C. and Gariepy, C., 1986. The tectonic evolution of the Abitibi greenstone belt of Canada; Geological Magazine, v.123, p.153-166.

Morasse, S., Wasteneys, H.A., Cormier, M., Helmstaedt, H., and Mason, R., 1995. A pre-2686 MA intrusion related gold deposit at the kiena mine, Val D'Or Quebec, Southern Abitibi subprovince; Economic Geology, v.90, p.1310-1321.

Mueller, W., Daigneault, R. Mortensen, J.K. and Chown, E.H. 1997. Archean terrane docking: upper crust collision tectonics, Abitibi greenstone belt, Quebec, Canada; Tectonophysics, v.265, p.127-150.

Mueller, W., Donaldson, J.A. and Doucet, P. 1994. Volcanic and tectono-plutonic influences on sedimentation in the Archean Kirkland Basin Abitibi greenstone belt, Canada; Precambrian Research, v.68, p.201-230.

Mueller, W., Daigneault, R., and Chown, E.H., 1997. Archean Terrane Docking along the Porcupine-Destor-Manneville Fault. Geological Association of Canada - Mineralogical Association of Canada, Joint Annual Meeting, Ottawa '97, Field Trip A7, Guidebook, 68 p.

Powell, W.G., Carmichael, D.M. and Hodgson, C.J., 1993. Thermobarometry in a subgreenschist to greenschist transition in metabasites of the Abitibi greenstone belt, Superior Province, Canada; Journal of Metamorphic Geology, v.11, p.165-178.

Robert, F. and Poulsen, K.H. 1997. World-class Archean gold deposits in Canada: an overview. Australian Journal of Earth Sciences, v. 44, p.329-351.

Robert, F. and Brown, A.C., 1984. Archean gold bearing quartz veins at the sigma mine, abitibi greenstone belt, Quebec: Part I. Geological relations and formation of the vein system; Economic Geology, v. 81, p.578-592.

Satterly, J., 1953. Geology of the North Half of Holloway Township; Ontario Department of Mines, v. 62, part 7, 38 p.

Thurston, P.C., 1991. Archean Geology of Ontario: Introduction, in Geology of Ontario, Ontario Geological Survey, Special Publication 4, part 1 p. 73-77.

Thurston, P.C. and Chivers, K.M., 1990. Secular variation in Greenstone Sequence development Emphasizing Superior Province, Canada; Precambrian Research, v.46, p.21-58.

Wilkinson, L., Cruden, A.R., and Krogh, T.E., 1999. Timing and kinematics of post-Timiskaming deformation within the Larder Lake - Cadillac deformation zone, southwest Abitibi greenstone belt, Ontario, Canada; Canadian Journal of Earth Sciences, v.36, p.627-647.

Wong, L., Davis, D.W., and Krogh, T.E. and Robert, F., 1991. U-Pb zircon ages and rutile chronology of archean greenstone formations and gold mineralization in the Val D'Or region, Quebec. Earth and Planetary Science Letters, v.104, p.325-336.

Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.